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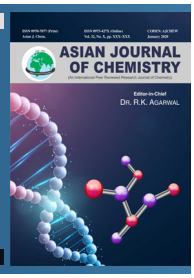


*REVIEW*

# Sterculia Gum: Chemical Structure, Composition and Physico-Chemical Properties

N. SHARMA[1,*] and T. SINDERPAL[1,2]

[1]Department of Physical Sciences, Sant Baba Bhag Singh University, Jalandhar-144030, India
[2]Department of Chemistry, Kanya Mahavidyalaya, Jalandhar-144001, India

*Corresponding author: Fax: +91 181 271155; E-mail: nishi.hpu@gmail.com

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Physico-chemical properties are crucial characteristics of hydrocolloids as they decide the applicability of them. Rheology of system, flow behaviour and mechanical properties make hydrocolloids suitable for food industry. Modification of consistency or texture properties of functional polymers also controls their sensory characteristics, thereby they become significant essences such as thickener, gelling agents, foaming agent, texture modifier, viscosifier, emulsifier, stabilizer and binder. Industrial and pharmaceutical applications are also controlled by some suitable physico-chemical properties of hydrocolloids. The polysaccharide gum exudates constitute a architecturally distinct class of complex biomacromolecules having unique physico-chemical properties. Due to their good bio/tissue compatibility, non-toxicity, they are extensively used in the field of tissue engineering, drug delivery and wound healing. Chemical and molecular architecture of hydrocolloids in turn controls their physico-chemical and functional properties. Sterculia gum is a substituted rhamnogalacturonoglycan (pectic) type exudate gum used as suspending agent, gelling agents, emulsifier, bulk laxative, dental adhesive, drug delivery agent and wound healing agent. It exhibits high water retention capacity, high viscosity and least solubility. Solutions of sterculia gum are viscoelastic and thixotropic. Sterculia gum has been recommended as effective wound dressing material as it can form a intensely adhesive gel when dispersed in minimum ammount of water. Owing to wide applications and distinctive properties of sterculia gum, present work is an endeavor to summarize the molecular organization, chemical configuration and physico-chemical properties of sterculia gum and the factors affecting physico-chemical properties of sterculia gum.

**Keywords: Sterculia gum, Thixotropy, Swellability, Viscoelastic behaviour.**

## INTRODUCTION

20th century witnessed the use of synthetic materials in different fields and have developed a huge market for synthetic materials [1]. Synthetic materials at one hand were easy to process and handle but at the same time have posed a very serious problem on our environment in terms of pollution in every strata of life. At the dawn of 21st century, synthetic materials have been replaced by semisynthetic and natural materials to minimize and limit the problems shown by synthetic materials [2,3]. The progress in environmental friendly materials led to the emergence of biomaterials to replace the synthetic ones. The advent of green technology has increased use of biomolecule applications in medicinal, pharmaceutical and food products. The repeated interest in exploitation of biomolecules is due to their biocompatibility, biodegradability and sustainability [4]. Various natural and synthetic biomaterials have applications in diverse fields *viz*. tissue engineering, biomedical engineering, drug delivery devices, paper and textile industry, food industry as an additive in foodstuff and nano-biotechnology [5].

The polysaccharide gum exudates constitute a architecturally varied class of complex biomacromolecules with extensive range of physico-chemical characteristics, commonly used in various industrial application like agro-food, textile, paper industry, as a dietary fiber, thickener, gelling agents, foaming agent, texture modifier, viscosifier, film, emulsifier, stabilizer for dispersions and binder. Due to their good bio/tissue compatibility and non-toxicity, they find applications in the field of tissue engineering for skin/ tissue regeneration, wound healing, drug delivery in their native form or in their chemically modified form [6,7]. Microporous polysaccharide

based hydrogels have find applications as drug delivery systems, anionic dyes/metal ions enrichment from polluted water [8] and as wound dressing materials [9,10].

The polysaccharide gums are important industrial raw materials due to their sustainability, biocompatibility, biodegradability and biosafety [11]. Unlike synthetic materials, polysaccharide gums are generally recognized as safe material. Polysaccharide gums are produced by a regular protection mechanism of the plant through a process called gummosis or due to any sort of injury to the bark or stem or by fungi and bacteria attack to the plant [12,13]. Different parts such as leaves, roots, stem of the plant secrete variety of gums, majority of them are exuded from the stem. Diverse plant families mainly Leguminosae, Sterculiaceae, Anacardiaceae, Combretaceae, Meliaceae, Rosaceae and Rutaceae secrete gum exudates in different forms [14]. Polysaccharide gums and mucilages are commonly used as a bulk dietary supplements, thickener, gelling agents, foaming agent, texture modifier, viscosifier, emulsifier, stabilizing agent, binder and drug delivery agent due to their favourable physico-chemical properties [5,15-18]. The physico-chemical characteristics of natural gums are basically controlled by their chemical compositions and molecular structures [17]. A report of World Health Organization affirmed sterculia gum as a safe food additive [19]. Due to wide applicability of natural gums, it is worthy to explore the correlation between structure, chemical configuration and physicochemical characteristics of polysaccharide gums. The present study is an attempt to summarized an account of structure, chemical configuration and properties of sterculia gum.

**Sterculia gum:** Sterculia gum is a natural heteropolysaccharide gum exudate obtained from the stem bark of *Sterculia urens*, of family Sterculiaceae [20,21]. The sterculia tree is a deciduous bushy tree native of dry deciduous forests in tropical climates. The genus sterculia comprises approximately 200 species distributed mainly in tropical and subtropical regions [22]. Commonly sterculia gum is known as sterculia, Indian tragacanth, bassora tragacanth, kadaya, mucara, kadira, katila, kullo, gular, gulu and kulu [23]. India has been world′s largest manufacturer as well as supplier of sterculia gum while Europe is the largest importer of sterculia gum. Majority of gum is obtained from *Sterculia urens*, indigeneous to north and central India. Apart from it, *Sterculia segitera*, from north African countries, Senegal and Mali also provide significant production. *Sterculia villora* in Sudan, India and Pakistan is the minor supplier. The annual production of sterculia gum in India is about 1500 MT [12,24]. For gum production, scars have been marked, eradicating a piece of bark or by drilling holes into the trunk. Exudation commences instantaneously and the exudate is permitted to harden on the tree trunk and removed as irregular shapes after complete solidification. It is then collected, washed, dried and then graded [24]. The flowers are yellowish-green in form of small inflorescence and produced in panicles in the axils of the leaves. The fruit split open when ripe and has six squarish, brown or black seeds [25]. An average tree can yield 1 to 4.5 kg per season for its lifetime. The best quality gum is harvested in April to June, before the monsoon season [26]. The chemical composition of gum samples are reasonably similar [27] although obtained from different species and diverse places of origin. The quality of gum fluctuates significantly due to variability in season of collection of gum [28].

**Grading and specification:** In earlier days, grading was based entirely on colour but now a days the grading is allocated as a function of bark and foreign matter (BFM) content. The system of grading varied from time to time [29]. Commercial sterculia gum is offered in five grades: top-quality selected, Superior no.1, Superior no. 2, fair normal quality and siftings [30-32]. The highest grade of sterculia gum is white, translucent and having minimum BFM. In contrast, nominal grades possess some impurities and having brown to dark brown colouration. Three-fourth of sterculia gum is used in pharmaceutical sector, 20 % is utilized technological sector and only 5 % is used in foodstuffs [25].

Sterculia gum is slightly acetous in odour and taste [33]. The colour of gum is dependent upon the grade ranging from colourless to a deep pink-brown and the pale yellowish. Purity and colour of sterculia gum define its final cost. Sterculia gum is available as granules and powder form of different dimensions [12]. There is approximately 12 to 14 % moisture content in powdered gum, but there will be higher weight loss on drying due to presence of some volatile substances [29,32,34]. In acidic medium, insoluble matter is upto 3 % and heavy metals are less than 40 μg/g. Ash contents has been reported less than 8 % [34]. On treatment with acidic medium, sterculia gum gives a pink colouration. With due course of time, on resting gum solution develops an acetous odour [35]. Powdered sterculia gum contains less than 1 % acid-insoluble ash and less than 3 % insoluble matter of bark [36]. Depending upon age and source of gum, there is about 8 % acetyl groups, with an acid number of 13.4-22.7. On aging, with rise in temperature and moisture content, there is release of free acetic acid [36].

**Molecular structure and chemical composition of sterculia gum:** Different researchers have explored and elaborated the molecular configuration of sterculia gum from time to time. Structurally, sterculia gum is a substituted rhamnogalacturonoglycan (pectic) type tree gums having complex acetylated branched structure of high molecular weight of about $9.5 \times 10^6$ Dalton determined by Svedberg ultracentrifuge method [36]. It contains partially acetylated glycanorhamnogalactouran units of D-galacturonic acid, D-glucuronic acid, D-galactose and L-rhamnose [37-39]. α-D-galactouronic acid is interconnected at C4 to α-L-rhamnose. D-galactose and D-glucuronic acid are substituted on the hydroxyl groups site [33]. Proportion wise, there is 43 % D-galacturonic acid, 13 % D-galactose, and about 15 % L-rhamnose [26]. Different forms of sterculia gum from different species show little variation in structure and composition [33,40,41]. Marvelys *et al*. [41] isolated polysaccharide from *Sterculia apetala*, which contained galactose, arabinose, xylose, galacturonic acid and glucuronic acid and its 4-O-methyl derivative. Sarathchandiran and Suresh [42] reported that structurally, sterculia gum is an acidic polysaccharide acetylated which consists of α-D-galacturonic acid and α-l-rhamnose as main backbone. There is β-D-galactose and β-D-glucuronic acid as residue units to the main chain to form polysaccharide. Further Wu *et al*. [43] extracted an acidic polysaccharide from sterculia seeds (Semen Sterculiae, Lychnophorae) consisting of approximately 40 % galacturonic acid,

11.4 % rhamnose, 17.5 % arabinose and 15.7 % galactose and trivial amount of 0.6 % xylose and just 0.4 % glucose. Infrared analysis confirms the presence of uronic acid in sterculia gum backbone upto 40 % [39]. Spectra shows a characteristic peak at 1722 $cm^{-1}$ which is correspond to C=O along with four bands at 1543, 1612, 1664 and 1724 $cm^{-1}$ [39].

Fungal degradation studies are also used for the confirmation of carbohydrate content of sterculia gum. Carbohydrate content, neutral sugar ratio of sterculia gum has been confirmed by degradation studies by Raymond and Nagel [40] using a fungal isolate, a *Cephalosporium* sp.. Fungal growth-studies specify that gum constitutes three different types of backbone chains. One chain composed of approximately 50 % of the total polysaccharide consists of repeating units of four galacturonic acid residues with L-rhamuose residue at the reducing end and α-D-galactose branches. Second chain (approximately 17 % of polysaccharide) consist of 50 % of galacturonic acid, 40 % of rhamnose and 10 % of galactose. Third chain comprises of D-glucuronic acid residues, which account for approximately 33 % of polysaccharide content [40]. Various studies confirmed that setrculia gum is composed of 55-60 % of neutral monosaccharide residues (galactose and rhamnose), 37-40 % uronic acid residues (galacturonic and glucuronic acid) and about 8 % acetyl groups. Singh and Sharma [44] have thoroughly elaborated molecular framework of sterculia gum.

Sterculia gum is composed of various components along with sugar residues. Various researchers from time to time have investigated the composition of different parts of tree. *Sterculia urens* seed kernels contains about 35 % protein content, 26 % fat content and 28 % polysaccarides [45]. Galla *et al*. [46] have carried out physico-chemical analysis of dehulled-defatted seed meal (DDSM) of *Sterculia urens*. The cotyledons have sufficient proportion of protein (30.88 %) and fat (39.2 %) content. Some indispensable minerals such as 39.5 mg/100g calcium and 995 mg/100g along with small fraction of iron and potassium were reported in DDSM. Protein content is highly soluble in basic pH at about pH 12 and display minimum solubility in pH 6. Solubility increases with increase in ionic strength in pH 2-12. Initially, DDSM is non-hygroscopic in nature as it had very less moisture content of about 5.16 %, which increases with rise in humidity (70 %). Dehulled-defatted seed meal possess approximately 67 g/100g of water holding capacity and about 114 g/100 g oil holding capacity and possesses excellent emulsification capacity of about 20 mL/g sample due to foam capacity (32 %) and foam stability (75 %) properties for extended period of time at room temperature [46,47].

Galla *et al*. [46] and Vinod *et al*. [48] have thoroughly investigated the protein profile and fat content of *Sterculia gum*. Vinod *et al*. [48] have derivatized sterculia gum as N-O-*bis*(trimethylsilyl)trifluoroacetamide (BSTFA) derivatives and methyl esters through transesterification and subsequently analyzed them through GC-MS method. Key amino acids present were aspartic acid and glutamic acid [46,48]. Apart from them sterculia gum contain glycine, leucine, proline and threonine. There is negligible faction of methionine, arginine, cysteine and histidine [46]. In another study, alanine, valine, methionine, tyrosine and tryptophan, were not detected in *Sterculia gum* [48]. Among, isoleucine, an essential amino acids was present beyond FAO/WHO requirements. Fatty acid composition present is about 87:13 ratio of saturated and unsaturated, respectively [48]. Analysis through GC-FID and GCMS analysis shows that total lipid content is composed of primarily with 31.72 % stearic acid, 28.83 % linoleic acid and 26.79 % palmitic acid. Two other fatty acids 4.98 % eicosadienoic acid and 2.96 % eicosatrienoic acid were also found [48].

Hamdani *et al*. [49] have characterized chemical composition of sterculia gum and apricot gum through electron spray ionization-mass spectrometry [49]. Apart from this phenolic content, encapsulating/chelating power and reducing power have also been studies. Sugar residues present includes galactose-6-phosphate, fructose-1,6-diphosphate, fructose-1-phosphate, 3-O-mthyl-glucose, laminaribiose, maltotriose, trehalose-6-phosphate, gentobiose, O-methyl-1-galactopyranoside, glucopyranose/xylose-1-phosphoric acid, α-D-mannopyranosyl-(1,2)-D-mannopyranose which are distinguishing component of sterculia gum. Sterculia gum had the lower content of total phenolic content as compared to apricot gum showing the excellent antioxidant properties of apricot gum [49].

**Physico-chemical properties of sterculia gum:** Physico-chemical properties are very crucial characteristics of polysaccharide gums. Natural gums have capability to modulate the rheology, flow behaviour (viscosity) and mechanical properties of a system which make them suitable for food industry. Hydrocolloids are imperative food additives due to the sensory properties provided by them and further decide their end use [50]. Similarly other industrial, pharmaceutical applications are also decided by some suitable physico-chemical properties. It is worthy to summerize the physico-chemical properties of sterculia gum. Sterculia gum is a hydrocolloid with profound swell ability, water holding capacity, high viscosity and low solubility [51,52]. Taste and odour of gum is due to acetyl groups present on its backbone which hydrolyses with time [32]. The acetyl contents also determine the solubility of gum which is different in different species.

**Solubility/solution properties:** Sterculia gum is a exceptionally hydrophilic hydrocolloid and least soluble gum in the category of commercial gums and in water forms highly viscous solution [53-55]. Extremely minute concentrations (< 0.02 % in cold water and 0.06 % in hot water) can form true solution of sterculia gum and forms viscous colloidal solution upto 5 % concentration [53]. It possess high water holding capacity second after carboxymethylcellulose held the largest amount of water after fermentation followed by gellan gum [56]. Verbeken *et al*. [24] reported that the sterculia gum swells up to 60-100 times of the original volume, producing a viscous dispersion. Acetyl groups are responsible for the swelling behaviour of sterculia gum. Deacetylation by alkali or ammonia treatment convert sweallable gum into a water soluble gum [53]. Le Cerf *et al.* [53] have characterized solution properties of sterculia gum using size-exclusion chromatography, light scattering and viscosity analysis in 0.1 M NaCl. It was observed that the acetylated gum acquire dense and branched conformation, but deacetylation led to fully expanded with random coil conformations. The gum characteristics can be modified using chemical treatment through alkali which converts water swellable gum into water soluble one. In 60 % alcohol, gum forms a viscous

solution [24]. Postulkova *et al*. [57] have analyzed the effect of NaOH, KOH and LiOH (except $NH_4OH$) on gum solubility. Solubility drastically increases due to removal of all acetyl groups from gum structure. Maximum solubilization occur at 1 mol $L^{-1}$ of NaOH, KOH and 2 wt.% dispersion of gum at room temperature.

**Viscosity and gel formation:** Viscosity of hydrocolloid gums is a crucial property responsible for the wide applicability of hydrocolloid especially in pharmaceutical and food industry as a stabilizer, binder and emulsifier, *etc*. [52]. Sterculia gum is an anionic hydrocolloid with high molecular weight.

Viscosity of sterculia dispersion lies in a range from about 120-400 cPs for 0.5 % dispersion and upto 10,000 cPs with 3% dispersions [58]. The viscosity of sterculia gum in water increases rapidly with concentration so that dispersion with a concentration of 2-3 % act as a gel. Higher concentration can be made as in bulk laxative applications by cooking sterculia gum in steam. This reduced dispersion viscosity so that 20-25 % dispersions can be made. Sterculia gum sols acquire their maximum viscosity at pH 8.5 but solutions become stringy above pH 8 [59].Various environmental factors affect viscosity of the gum *viz*. ageing, high temperature, high humidity and storage decreases viscosity of gum which is due to loss of acetic acid. Therefore storage temperature should not exceed 25 ºC [60]. Sterculia gum forms a viscous solution when dispersed in cold water as compared to hot water [26]. Its viscosity is reduced on heating and on addition of an electrolyte. Therefore, electrolytes should be mixed in fully hydrated gum [61]. Viscosity of gum remains unaltered for several days but being organic in nature is vulnerable to bacterial attack. Glickman [62] reported that viscosity increases with the hydration prior to pH adjustment.

Viscosity of sterculia gum is affected by particle size of gum also. Nussinovitch [30] reported that the evenness of gum is dependent upon particle size which can be modified by continued stirring to get a smooth consistency and decreased viscosity. As soon as dispersion become finer, it results in increase in viscosity, which attributes to swelling of fine particles of colloid at faster rate. Coarse particles of 80 mesh dimensions, viscosity was attained gradually due to swelling of the particles. With large gum particles, free surface water behave as lubricating system due to which swollen gum particles starts sliding one past the another. As particle size decreases, gum particles are close to one another and there is firmly held and more rigid water, thus adhering gum particles more firmly and show greater viscosity [63,64]. When sterculia gum dispersions are dried, they form a brittle film that can be plasticized with glycerol. At concentration of 20 % or more, sterculia gum dispersions are adhesive and capable of forming strong bonds [43].

**Rheological properties:** Rheology of a material account for the flow behaviour and distortion of matter as a result of flow. Rheological properties determine the shear rate and rate of deformation of materials. The way of mixing, mode of settling of coatings and which tools can be used to disperse material are the characteristics decided by the rheological characteristics of a material. Rheology of gums is very crucial property which decides the applicability of gums as food additives especially as binder and thickening agents. Sterculia gum solutions are thixotropic *i.e.* viscosity increases with the increase in concentration and addition of salts decreases viscosity of solution [65]. Thixotropic liquids have time controlled response to shear/strain rate for extended period. On shaking, easily get liquified but get solidified when shaking has stopped. Sterculia gum display enhanced thixotropic property at elevated temperature and concentrations [52]. Fine dispersions of sterculia gum display Newtonian flow and shear thinning behaviour in concentrations ($< 0.5$ %) and ($0.5\ \% < c < 2\ \%$) [66], respectively. In Newtonian fluids, shear rate to shear stress ratio become constant which means viscosity is independent of shear strain rate and do not have a constant ratio between their shear rate and shear stress. The flow behaviour of non-Newtonian fluids are unpredictable and viscosity of the material is highly capricious. Rheological property of gums is also dependent upon ionic strength of medium, concentration, pH and temperature. There is gradual thickening as well as rise in viscosity with increase in concentrations of the dispersing medium due to increase in molecular weight of gum and results into a spreadable paste or gels [66,67]. Steady-shear rheological measurement showed increase in pseudoplasticity of gums with gradual rise in concentration from 1-10 % (w/v). In such materials there is instantly decline in viscosity with rise in shear strain rate and get easily mixed and flow. This behaviour of materials is also intensifies with concentration. It also exhibited a liquid-like property at a concentration of 10 % at 25 ºC and are unable to form a gel. However, the gelation take place only in the presence of some co-solutes. Sugars, as co-solutes upto 60 % in pH < 3.5 and at 37 ºC exhibited remarkable viscoelastic fluid behaviour [43]. The swollen dispersions can not sustain long stirring and shear treatment consequently results in to drop in viscosity. Rheological study and surface tension measurements show that *Sterculia apetala* gum produce highly viscous dispersions of good viscoelasticity [68,69]. Rheological properties of sterculia gum-alginate blends have been studied applying creep and oscillation experiments. Age of sterculia gum strongly affects viscoelastic properties of the blends but with fresh gum give excellent blend synergy, which results in uniform blend networks [70]. Sterculia gum forms true gels only at concentration greater than 4 % and gel strength decreases with addition of NaCl [71]. Silva *et al*. [72] analyzed the influence of salt on rheological behaviour of *S. striata* and *S. urens* gums and subsequent gel like mechanical spectra was recorded which shows $G' > G''$ (where $G'$ is elastic moduli and $G''$ is viscous moduli). There is little frequency controlled behaviour indicating that a gel network is formed which is stabilized by presence of acetyl groups [73]. Flow curves for rheological bulk characterization of *Sterculia apetala* gum solutions in 1 M NaCl validated a shift from Newtonian to non-Newtonian behaviour when concentration rises from 0.5 % to 1 % w/v and at 2 % w/v, become gel-like viscoelastic behaviour. Due to such behaviour, *Sterculia apetala* gum is used as thickening agent and its dispersions exhibited surface activity [67]. Chauhan *et al*. [68] characterized the flow behaviour of sterculia gum by time independent rheology analysis at variable temperature under shear using a controlled stress rheometer. There is a temperature controlled behaviour. There is constructive yield stress values which are autonomous of wall slip effects and have thermogelation at elevated temperatures at different concentrations.

Strong shear-thinning behaviour, emulsifying activity, high viscosity have been achieved in hybrid mixed formulations of sterculia gum. There is formation of uniform small droplets in both aqueous and O/W emulsion system. The conjugation process also control the droplet size distribution of gum. When an isolate of soy protein is mixed with gum sterculia, the behaviour of hybrid conjugate in aqueous and oil-in-water (O/W) emulsions systems have been studied. Conjugation was achieved at 60 ºC with 75 % relative humidity for 3 days [52].

**pH stability:** Indian Sterculia gum solution of 1 % concentration have pH of about 4.4-4.7 range. African sterculia gum has pH of range 4.7-5.2 [30]. On addition of alkali, pH increases upto pH 7 or 8, due to buffering behaviour of Sterculia gum, pH gradually declines to acidic side. In basic pH, alkali irreverisibly transmutes the short-bodied solutions into a extended stringy mucilage as a result of saponification [26]. Deacetylation results into increase in ropiness of polymer chains and viscosity. High uronic acid content of sterculia gum favours the maintenance of acid conditions and counter attack hydrolysis in 10 % HCl solution for atleast 8 h [29,61]. Sterculia gum is soluble at all pH values but has maximum solubility at pH 6-8. Extraordinary viscosities and pH constancy are obtainable if gum hydration should be done prior to pH adjustment [62]. The solution colour lightens in acidic media and darkens in alkaline solutions because of the presence of tannins.

**Emulsifying properties:** Gums act as emulsifiers and suspending agents as they can efficiently stabilize the emulsions through interfacial absorption and the successive formation of firm films of good tensile strength that repel coalescence of droplets. They form strong multilayer coating around oil globule to stabilize emulsions [14]. Owing to emulsifying property, Sterculia gum possess about 69 emulsification index at a much higher concentration (35 mg $mL^{-1}$) [73]. Sterculia gum form more stable butyl phthalate emulsion as compared to tragacanth gum and acacia gum. Sterculia-stabilized emulsions break unevenly [74]. Shekarforoush *et al*. [52] have investigated the effects of heat and microwave treatment on the material properties of sterculia gum in aqueous and oil-in-water (O/W) emulsion systems. Emulsifying action was considerably enhanced under heat and microwave treatments. Microwave treatment results in smallest gum droplet size, most anticipated particle consistency and emulsion formed was of high stability. It was also observed that such gum emulsions were stable upto 30 days of storage and after 10 days, there was gradual phase separation due to decline of repulsive forces between emulsion droplets, thus affecting their collision and subsequently dropping of emulsion stability [52].

**Compatibility:** Hydrogels swells up in aqueous media, this exhibit its thermodynamic compatibility with water. High water content of hydrogels subsidizes to their biocompatibility. This is the capacity of a material to accomplish with an suitable host response in a specific application [75]. Biocompatibility is the property which make polysaccharides a versatile material with extensive applications in biomedical and clinical fields [76].

Sterculia gum has good compatibility with hydrocolloids, proteins and carbohydrates [77]. Sterculia gum and alginate being acidic in nature, synergic association would be expedited by reducing inter-chain repulsions or ionic strength. A 75 % aged gum and minimum salt content give maximum synergy between aged sterculia gum and alginate [69]. In combination with acacia gum or carrageenan at the level of about 0.01-0.02 %, while 0.1-0.9 % sterculia gum is used and being very effective as staling proof agent for baked goods [29].

**Mucoadhesive property:** Sterculia gum has very effective mucoadhesive behaviour responsible for its use in mucosal drug delivery. High molecular weight, high viscosity and anionic character of sterculia gum are the factors responsible for its mucoadhesive property [78]. Polyanionic polymer and water-insoluble polymer is preferred over neutral or polycationic polymer and water-soluble polymer for mucoadhesive dosage forms [79,80]. It prolonged gastrointestinal absorption of drug during drug delivery [81]. Owing to mucoadhesivenss, sterculia gum remain intact on the non-oral lesion and in intra-oral ulcers. It is preferred as lesion dusting system due to its availability as powdered medication form [82]. Sterculia gum is a worthy coating agent and has excellent wet-adhesive strength. A hydrogel having sterculia gum greater than or equal to 15 % by weight, absorb enormous extent of water and maintain their consistency [83].

Ouk *et al.* [84] proposed a composition for preventing, alleviating or treating oral cavity diseases comprising a sterculia lychnophora extract as an active ingredient. According to the present invention, the sterculia lychnophora extract is effective in inhibiting the proliferation of oral bacteria, inhibiting acid generation of oral bacteria, effects in inhibiting biofilm formation of oral bacteria on a surface of artificial teeth and natural teeth. Liwei *et al*. [85] revealed a buccal lozenge of boat sterculia seed for treating acute or chronic inflammation of upper respiratory tract prepared from extract of boat sterculia seed, mint oil, salt sugar and cane sugar having advantages of high curative rate, 100 % of total effective rate, no recurrence and no toxic by-effect [85].

**Bioactivity:** Sterculia gum is a biologically active gum and shows a momentous increase in the serum HDLcholesterol/cholesterol ratio and cholesterol concentrations in faeces in rats and anti-inflammatory effect in murine. Afrose *et al*. [86] compared hypocholesterolemic effect of sterculia root saponin in rats that were initially fed on cholesterol rich diet by conducting study on sixty male Wister-Imamichi rats [86].

Ai *et al*. [87] have isolated hydrophilic polysaccharides from seeds of sterculia through extraction, precipitation and fractionation. Two components have been isolated *viz.*, neutral an acidic one using anion-exchange chromatography. Bioactivity of acidic and neutral extract have been evaluated on ear edema made by dimethylbenzene and cotton pellet-induced granuloma tissue. Acidic extract possessed a powerful concentration dependent anti-inflammatory activity and can be used as a natural cure due to its anti-inflammation effects [87]. Foster *et al*. [88] have developed *in situ* gastro-retentive gels for rodents using sodium alginate and sterculia gum. Gastric retention of gel have been studied for 1-8 h. This formulation may be a beneficial device to achieve gastric retention for effective therapy [88].

Padil and Eermik [5] have synthesized CuO nanoparticles incorporated sterculia gum using $CuCl_2{\cdot}2H_2O$ and their antibacterial activity on *E. coli* and *S. aureus* have been evaluated. It was observed that nanoparticles were stable and possess

momentous antibacterial action on both bacteria. Maximum zone of inhibition was observed with small size particles as compared to larger sizes of synthesized copper oxide nanoparticles [5]. Rani and Rajasekharreddy [89] have studied that silver-(protein-lipid) nanoparticles synthesized with seed extract from *Sterculia foetida* have potent mosquito larvicidal activity an antiproliferative activity thus become promising candidate for treatment of cancer cell lines. Triterpenoid isolated from *Sterculia villosa* also possess *in vitro* as well as *in vivo* antileishmanial and immunomodulatory activity of visceral leishmaniasis. It can act as a powerful immunomodulatory agent [90].

**Factors affecting physico-chemical properties**

**Effect of salt concentration:** Natural gums act as a polyelectrolyte in food industry and quickly respond to salts present in food [91]. It causes variation in rheological and biological behaviour of gums, which may be due to fluctuation in molecular conformations of gum. Solution of gum without salt has high viscosity which attributes to fully expanded molecular structure. At concentration of salt, there is electrostatic screening effect of ions around the gum, thus decreases the extension of polymeric chains which is responsible for drop in viscosity. On increasing the salt concentration, anionic residues on gum get exposed and neutralized with cations of the salts resulting in collapsing of polymeric chains to a more compact coil. There is decrease in hydrodynamic volume of the gum and accordingly further decline in viscosity [92,93]. Low concentration of salt, cations could promote a generic shielding of electrostatic repulsive forces between anionic chains of *Sterculia striata* and *Sterculia urens*, thus assisting multivalent counter ion interactions with increased gel strength [72]. Both gums formed 'true' gels with thermos-reversible behaviour. With monovalent salts (LiCl, NaCl, KCl) when added to native *S. striata* and deacetylated gum polysaccharide make stronger gel. The gel strength decrease with increase of cationic radius of divalent salt [72].

**Effect of heat and microwave treatments:** Sterculia gum dispersion is sensitive to heat treatment. Glickman [62] reported that on heating sterculia gum dispersion, the solubility increases and there is loss of viscosity permanently. In cold water, there is possibility of formation of homogenous gum solution upto concentration of 4-5 %, but with rise in temperature under pressure, a smooth and homogeneous, transluscent solution is obtained at high concentrations upto 18-20 %. Heat and microwave actions also affect rheological behaviour of sterculia gum. Shekarforoush *et al*. [52] have investigated the effects of heat and microwave treatments on the solution properties of gum in the aqueous system as well as in oil-in-water emulsion systems. Heating decreases particle size, particle homogeneity, moisture content, viscosity, porosity and emulsifying activity of gum. But on microwave treatment, all these properties were considerably enhanced due to substantial influence on the micro-structure of gum where as viscoelastic properties decreases.

**Effect of γ-radiation:** Irradiation with γ-irradiation results in increase in water solubility of sterculia gum and decrease in swellability. Le Cerf *et al*. [94] have studied the influence of high energy γ-irradiation on the swelling behaviour of sterculia gum [94]. There is significant increase in the water solubility and decline in viscosity and swelling when sterculia gum was exposed to radiation doses up to 5 kGy from a $^{60}$CO source. γ-Irradiation affect the quaternary structure of gel which is basically control the swelling properties, but primary structure is unaltered [94]. Radio-sterilization of powdered gum from *S. urens* and *S. setigera* reduce microbiological contamination [94]. The viscosity of sterculia gum and tragacanth is unaffected by γ-irradiation at low doses (< 1 kGy). Viscosity of sterculia gum of 1 % concentration, when irradiated doses < 10 kGy showed pseudoplastic behaviour which approached Newtonian with increasing irradiation dose [95].

Singh and Sharma *et al*. [96] have investigated the influence of absorbed dose on water absorption capacity, solubility, pH/emulsion stability, rheology as well as FTIR, XRD, SEM, absorbance of sterculia gum. It was reported that the solubility increases where as swellability decreases with rise in absorbed dose. The acidity and emulsion stability was improved and apparent viscosity initially increases with increase in dose rate than decreases with steady fashion with further increase in total absorbed dose. Rheology of gum solution moved to Newtonian from non-Newtonian behaviour with rise in dose [96].

Hamdani *et al*. [97] have studied the influence of γ-irradiation on physico-chemical behaviour of sterculia gum along with acacia and apricot gum. Irradiation treatment decreases the molecular weight of gum. Solution properties like water absorption, swelling, solubility index and emulsifying behaviour increased with the intensification in irradiation dose (0-5 kGy). From FTIR study, absorbance of functional groups like -OH, -COOH, units also amplified upon irradiation in acacia gum and sterculia gum [97]. The copolymerization of 3,3-dimethyl acrylic acid onto sterculia gum was achieved through diode laser irradiation and is more effective method than by an aqueous redox initiator solution of cerium(IV) ammonium nitrate [98].

## Conclusion

The exclusive properties of sterculia gum *viz*. high swelling, high water retension capacity, tunable viscosity and low solubility makes it a suitable candidate for pharmaceutical applications. Despite unique characteristics, the properties of sterculia gum can be further modified with appropriate reagent to form intelligent biodegradable material with improved physical and chemical properties. Hence, there is tremendous scope to explore the various processes of structure modification of sterculia gum. Secondly, exhaustive study can also be done to summarize the potential applications of modified sterculia gum in biomedical engineering, tissue engineering, nano-biotechnology, food, textile, paper industries, *etc*.

## CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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